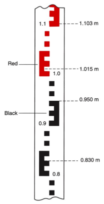

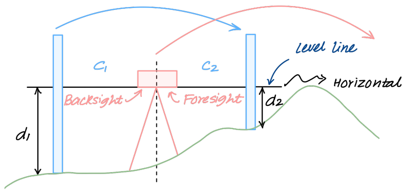

CE331 Lab 4 : Levelling Using Auto Level

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Objective

Lab Exercise 4 : Leveling using Auto Level

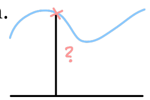
- To perform a leveling operation using an Automatic Level
- To understand the operation of an Automatic Level instrument
- To report the quality of work based on misclosure
- To perform adjustment or error distribution of closing error

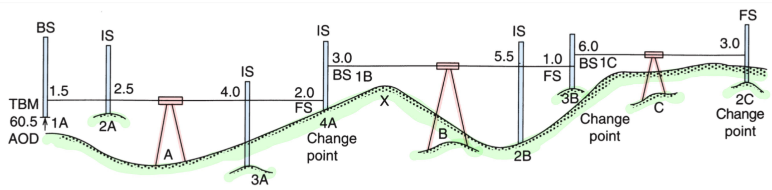
Equipment

- Nikon Automatic Level
- Leveling Staff
- Tripod
- Level Field Book

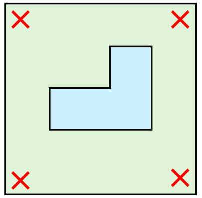
Key Terms in Vertical Control

- **Leveling** is the process of finding elevations of points or their differences in elevation.
- **Level line** or **surface** is normal to gravity at all points, often ellipsoidal.
- **Horizontal line** or **surface** is normal to gravity at a particular point.
- **Datum** is a reference surface to measure elevations, usually mean sea level (MSL).
- **Benchmark (BM)** is a permanent point with a known height above the datum.
- **Reduced level (RL)** of a point is its height above or below a datum.



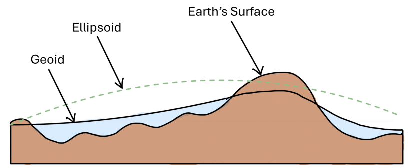


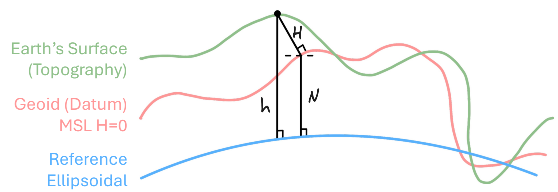
Courtesy: Schofield and Breach.



Important Surfaces in Geodesy

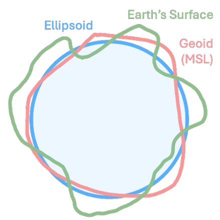
- **Earth's Surface (Topography)**
  - The actual terrain of the Earth with varying elevations.
- **Geoid Surface (Datum)**
  - An equipotential surface of Earth's gravity field.
  - Approximates Mean Sea Level (MSL) where H = 0.
- **Reference Ellipsoid**
  - A mathematically defined, smooth surface.
  - Used as a reference for geographic coordinates and ellipsoidal heights.





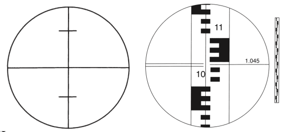
$$H = h - N$$

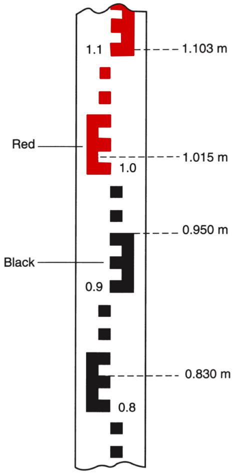
H: Orthometric Height
h: Ellipsoidal Height
N: Geoid Height



Leveling Staff

- Specifications:
  - Marked in meters & centimeters
  - Alternate black-red meter lengths on white
  - Smallest graduation: 0.01 m
  - Take readings to nearest millimeter for accuracy
  - Circular bubble to maintain vertical position
  - Telescopic or socketed in 3-4 sections for portability
  - Typically follows British Standard (BS 4484) E-pattern





Courtesy: Schofield and Breach.

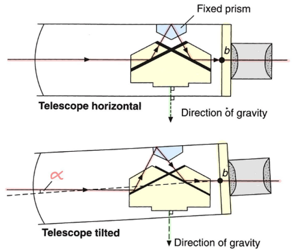
How to calculate distance leveled using stadia readings?

- Tachometric Distance Calculation: $d_{levelled} = (US - LS) \cdot 100$
  - $d_{levelled}$: Distance leveled (meters)
  - US: Upper stadia reading (meters)
  - LS: Lower stadia reading (meters)
  - $K = 100$ is the stadia constant

Auto Level

Automatic Level

- Why "Automatic"?
  - Automatically adjusts for small tilts (collimation errors) within ±20' using a compensator
  - Despite tilt of telescope, we see the same point on staff
- Only requires leveling
- No need for centering

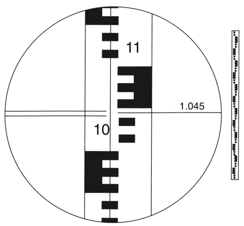


Courtesy: Schofield and Breach.

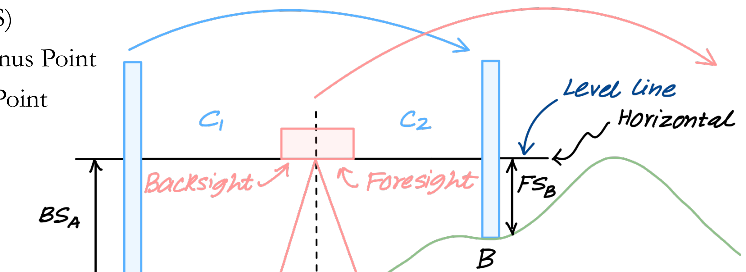
Principle of Leveling

How to perform Leveling?

- Back Sight (BS) or Plus Point
- Intermediate Sight (IS)
- Fore Sight (FS) or Minus Point
- Changing / Turning Point



Courtesy: Schofield and Breach.

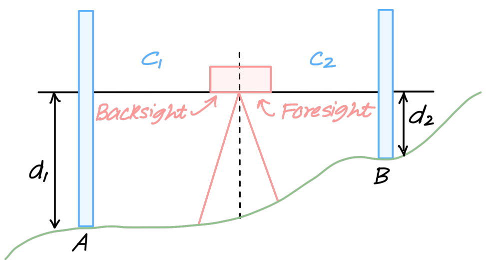


$$HI = H_A + BS_A$$
$$HI = H_B + FS_B$$
$$H_B = H_A + BS_A - FS_B$$

Key Considerations

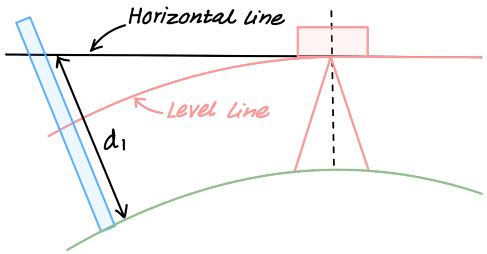
Balancing of FS and BS

- Keep the horizontal distance of BS and FS (c_1 and c_2) approximately equal
  - Collimation error cancels out



Effect of Earth's Curvature

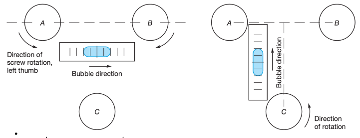
- c_1 and c_2 should not be too large
  - Horizontal line ≠ Level line over long distances



Procedure

Setup

- Step 1: Setup the tripod on stable ground.
- Step 2: Mount the Automatic Level on the tripod.
- Step 3: Use the foot screws and circular bubble to level the instrument.



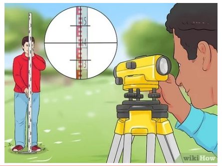
Courtesy: Wolf and Ghilani.

Readings

- Step 1: Take the first reading (Backsight) from a known RL near the GI lab (BM).
- Step 2: Conduct fly leveling to determine RLs of features e.g., electric poles, markings.
- Step 3: Take the final reading (Foresight) at the starting point near the GI lab (BM).

Recording Observations in Levelling Field Book

- Method 1: Rise and Fall Method
- Method 2: Height of Instrument / Height of Collimation Method

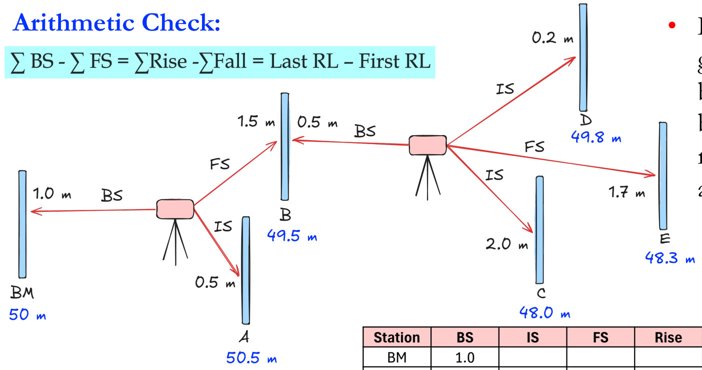


Rise and Fall Method

Arithmetic Check:

∑ BS - ∑ FS = ∑Rise -∑Fall = Last RL – First RL

- Determine whether the ground is rising or falling by comparing successive backsight and foresight readings, adjusting the RL accordingly.



$\sum BS - \sum FS = -1.7$
$\sum Rise - \sum Fall = -1.7$
$Last\ RL - First\ RL = -1.7$

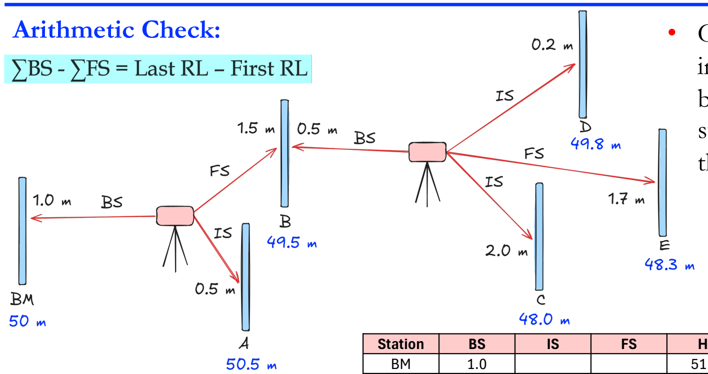
Station	BS	IS	FS	Rise	Fall	RL	Remarks
BM	1.0					50.0	Benchmark (Known RL)
A		0.5		0.5		50.5	Rise = 0.5
B	0.5		1.5		1.0	49.5	Falll = 1.0
C		2.0			1.5	48.0	Fall = 1.5
D		0.2		1.8		49.8	Rise = 1.8
E			1.7		1.5	48.3	Fall = 1.5
Sum	1.5		3.2	2.3	4.0		

Height of Instrument Method

Arithmetic Check:

∑BS - ∑FS = Last RL – First RL

- Calculate the height of the instrument by adding the backsight to the RL, then subtract foresight to find the new RL.



$\sum BS - \sum FS = -1.7$
$Last\ RL - First\ RL = -1.7$

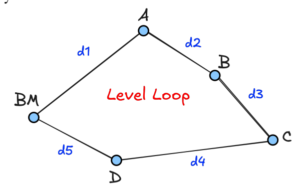
Station	BS	IS	FS	HI	RL	Remarks
BM	1.0			51.0	50.0	Benchmark (Known RL)
A		0.5			50.5	
B	0.5		1.5	50.0	49.5	Turning Point
C		2.0			48.0	
D		0.2			49.8	
E			1.7		48.3	Last Point
Sum	1.5		3.2			

Misclosure Error

How to check the levelling accuracy?

- Close the loop
  - Return to the original BM or connect to another known BM to detect any misclosure.

$Misclosure = H_{BM} - BM = Computed\ RL\ of\ BM\ - Known\ RL\ of\ BM$



Acceptable Error

- Determined by project requirements or predefined standards.

Closure Tolerances

- Distance Based

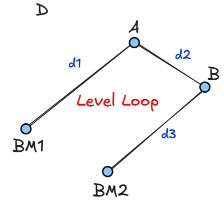
$Tolerance\ (mm) = c\sqrt{k}$

  - k = Distance levelled (in km)
  - c = Constant (2 to 12 mm, based on desired accuracy)

- Set-up Based

$Tolerance\ (mm) = c\sqrt{n}$

  - n = No. of instrument set-ups
  - c = Constant (±5 mm)
  - *Typically used for construction survey*



Quality of Work

Misclosure Error ≤ **Closure Tolerance**

$Misclosure = H_{BM} - BM$ ≤ $Tolerance\ (mm) = c\sqrt{k}$

Quality of Work	Purpose	c
Highest	Geodetic leveling, special surveys	1
Precise	Geodetic leveling, widely distributed benchmarks	4 (5)
Accurate	Principal benchmarks, extensive surveys	12 (10)
Ordinary	Construction, location surveys	24 (25)
Rough	Reconnaissance, preliminary surveys	100

Courtesy: Dr. Onkar Dikshit, Geoinformatics Lab, IIT Kanpur

Error Distribution (Adjustment)

How the closing error can be distributed/adjusted?

Approach 1:

- Based on Number of Points
  - Apply error correction to each point based on the number of points (n)

    $C_i = \frac{-M}{n}$
  - Adjusted elevation at CP

    $\bar{H}_i = H_i - \frac{M}{n}$
  - Adjusted elevation at BM

    $\bar{H}_{BM} = H_{BM} - M = BM$
  - Apply the same correction at intermediate points as at CPs.

Approach 2:

- Based on Distance
  - Distribute error correction based on distance leveled (d_i).

    $C_i = -\frac{d_i M}{\sum d_i}$
  - Adjusted elevation at CP

    $\bar{H}_i = H_i + C_i$
  - Adjusted elevation at BM

    $\bar{H}_{BM} = H_{BM} + C_i = BM$

Note: The purpose of adjustment is to ensure that the geometric constraints are satisfied. It doesn't increase accuracy of observations.

Example Level Book : Rise and Fall

BS	*IS*	*FS*	*Rise*	*Fall*	*RL*	*Distance*	*Remarks*	
1.5					60.5	0	TBM (60.5)	1*A*
	2.5			1.0	59.5	30		2*A*
	4.0			1.5	58.0	50		3*A*
3.0		2.0	2.0		60.0	70	CP	4*A* (1*B*)
	5.5			2.5	57.5	95		2*B*
6.0		1.0	4.5		62.0	120	CP	3*B* (1*C*)
		3.0	3.0		65.0	160	TBM (65.1)	2*C*
10.5		6.0	9.5	5.0	65.0		Checks	
6.0			5.0		60.5		Misclosure	0.1
4.5			4.5		4.5		*Correct*	

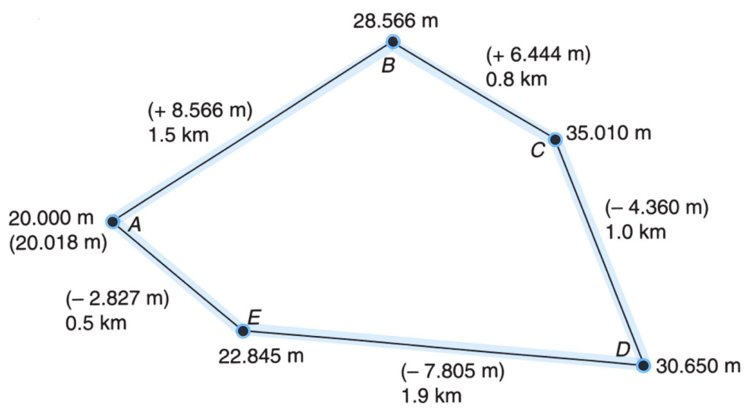
Courtesy: Schofield and Breach.

Example Level Book : Height of Phase of Collimation (HPC)

BS	*IS*	*FS*	*HPC*	*RL*	*Remarks*	
1.5			62.0	60.5	TBM (60.5)	1*A*
	2.5			59.5		2*A*
	4.0			58.0		3*A*
3.0		2.0	63.0	60.0	Change pt	4*A* (1*B*)
	5.5			57.5		2*B*
6.0		1.0	68.0	62.0	Change pt	3*B* (1*C*)
		3.0		65.0	TBM (65.1)	2*C*
10.5	12.0	6.0		65.0	Checks	
6.0				60.5	Misclosure	0.1
4.5				4.5	*Correct*	

Courtesy: Schofield and Breach.

Example: Level Loop



Example: Level Adjustment

$Misclosure = 100.008 - 100 = 0.008\,m = 8\,mm$

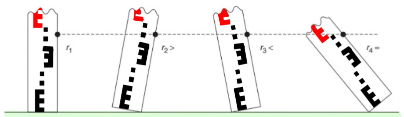
Back Sight (BS)			Fore Sight (FS)			HI	RL	Remarks	Distance			Cumulative Distance	Corrected RL
LS	MS	US	LS	MS	US				D1	D2	Total		
0.402	0.480	0.557				100.480	100	BM					
0.424	0.508	0.591	3.258	3.367	3.478	97.621	97.113		15.5	22.0	37.5	37.5	97.113
2.387	2.458	2.528	1.800	1.879	1.958	98.200	95.742		16.7	15.8	32.5	70.0	95.741
1.673	1.723	1.774	1.673	1.723	1.774	98.200	96.477	CP1	14.1	10.1	24.2	94.2	96.476
1.939	2.094	2.249	2.387	2.457	2.527	97.837	95.743		10.1	14.0	24.1	118.3	95.742
1.562	1.682	1.802	1.790	1.960	2.130	97.559	95.877	CP2	31.0	34.0	65.0	183.3	95.875
0.445	0.510	0.578	0.329	0.475	0.621	97.594	97.084	CP3	24.0	29.2	53.2	236.5	97.082
1.667	1.800	1.932	2.522	2.610	2.699	96.784	94.984		13.3	17.7	31.0	267.5	94.981
2.899	3.044	3.191	0.050	0.229	0.409	99.599	96.555	CP4	26.5	35.9	62.4	329.9	96.552
3.326	3.410	3.492	1.612	1.741	1.871	101.268	97.858		29.2	25.9	55.1	385.0	97.854
1.549	1.742	1.929	0.560	0.699	0.838	102.311	100.569	CP5	16.6	27.8	44.4	429.4	100.565
0.922	1.110	1.292	0.519	0.700	0.822	102.721	101.611	CP6	38.0	30.3	68.3	497.7	101.606
0.812	0.968	1.122	1.868	2.061	2.259	101.628	100.66		37.0	39.1	76.1	573.8	100.655
0.535	0.758	0.980	1.039	1.300	1.562	101.086	100.328	CP7	31.0	52.3	83.3	657.1	100.322
1.142	1.281	1.420	1.972	2.189	2.405	100.178	98.897		44.5	43.3	87.8	744.9	98.890
2.086	2.215	2.345	1.101	1.201	1.302	101.192	98.977	CP8	27.8	20.1	47.9	792.8	98.969
			1.069	1.184	1.299	100.008	100.008	BM	25.9	23.0	48.9	841.7	100

Sources of Error

Instrumental Errors

- Line of sight not horizontal (collimation error): Minimized by equalizing sight distances
- Parallax & Staff Graduation Errors: Calibration is key.
- Tripod Stability: Ensure firm and secure setup.

Observational Errors

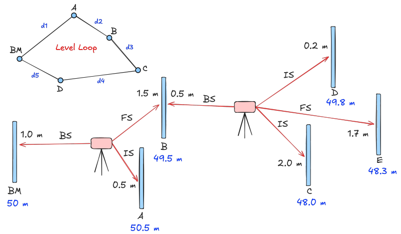


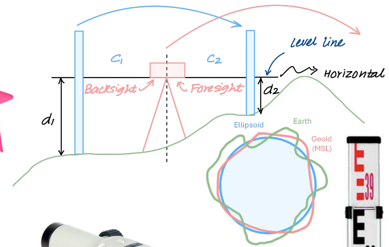
- Staff not vertical: Hold vertically; use a staff bubble.
- Reading Errors: Limit sight distances to 25-30 m for clarity.
- Booking Errors: Record data carefully and verify observation.

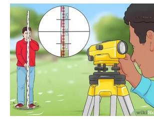
Natural Errors

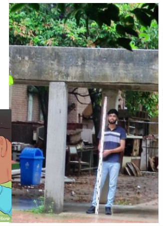
- Curvature and Refraction: Minimize by equal sight distances and avoiding large distances.
- Environmental Factors: Wind and heat shimmer can impact accuracy.

Courtesy: Schofield and Breach.









Comments and Questions?

Email: amanks20@iitk.ac.in

Courtesy: Dr. Onkar Dikshit, Dr. Salil Goel, Dr. Bharat Lohani, Geoinformatics Lab, IIT Kanpur.